J-PARC High Intensity Neutrino Beam

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on behalf of T2K Beam Group

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- **Current Status**
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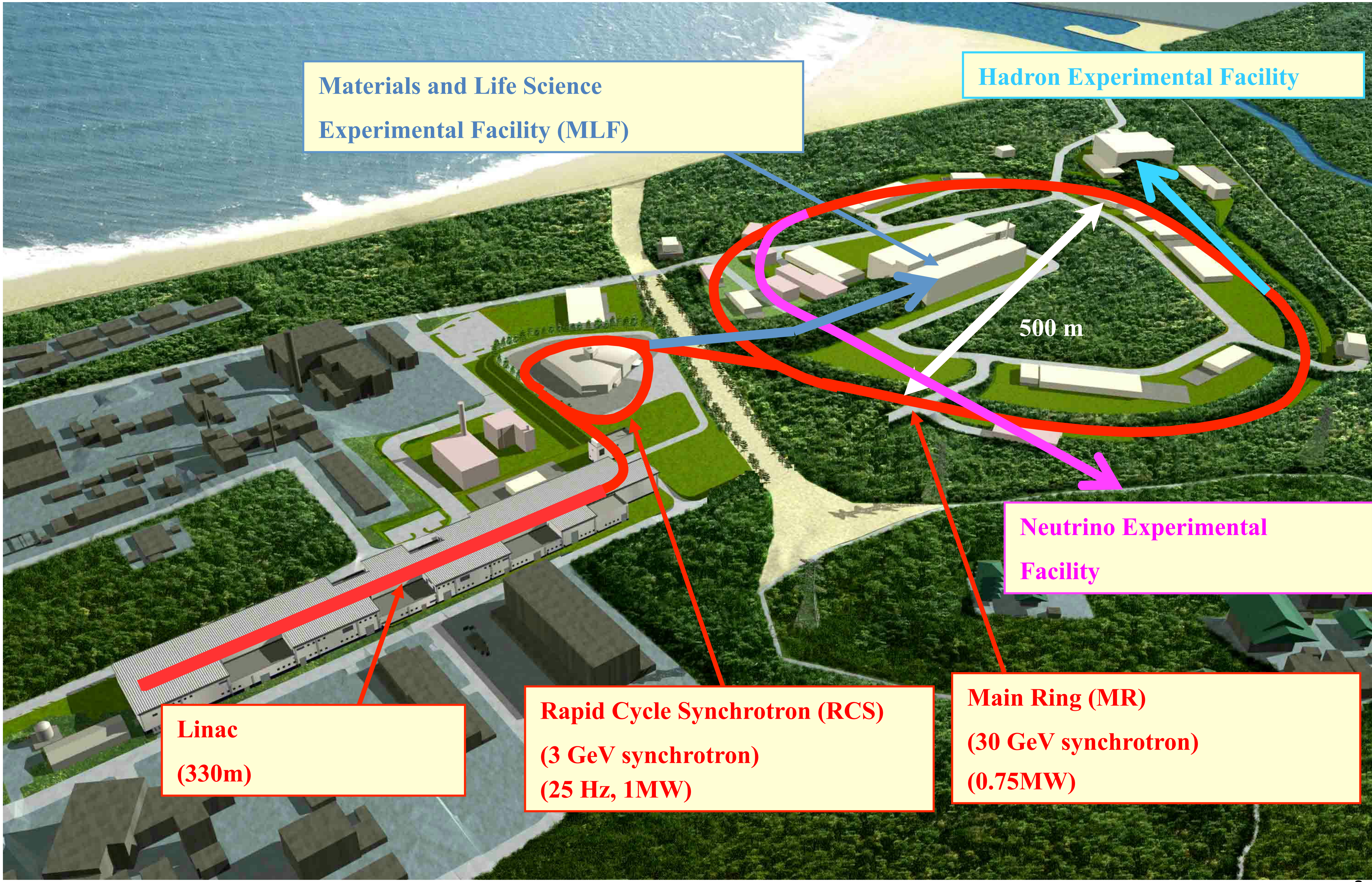
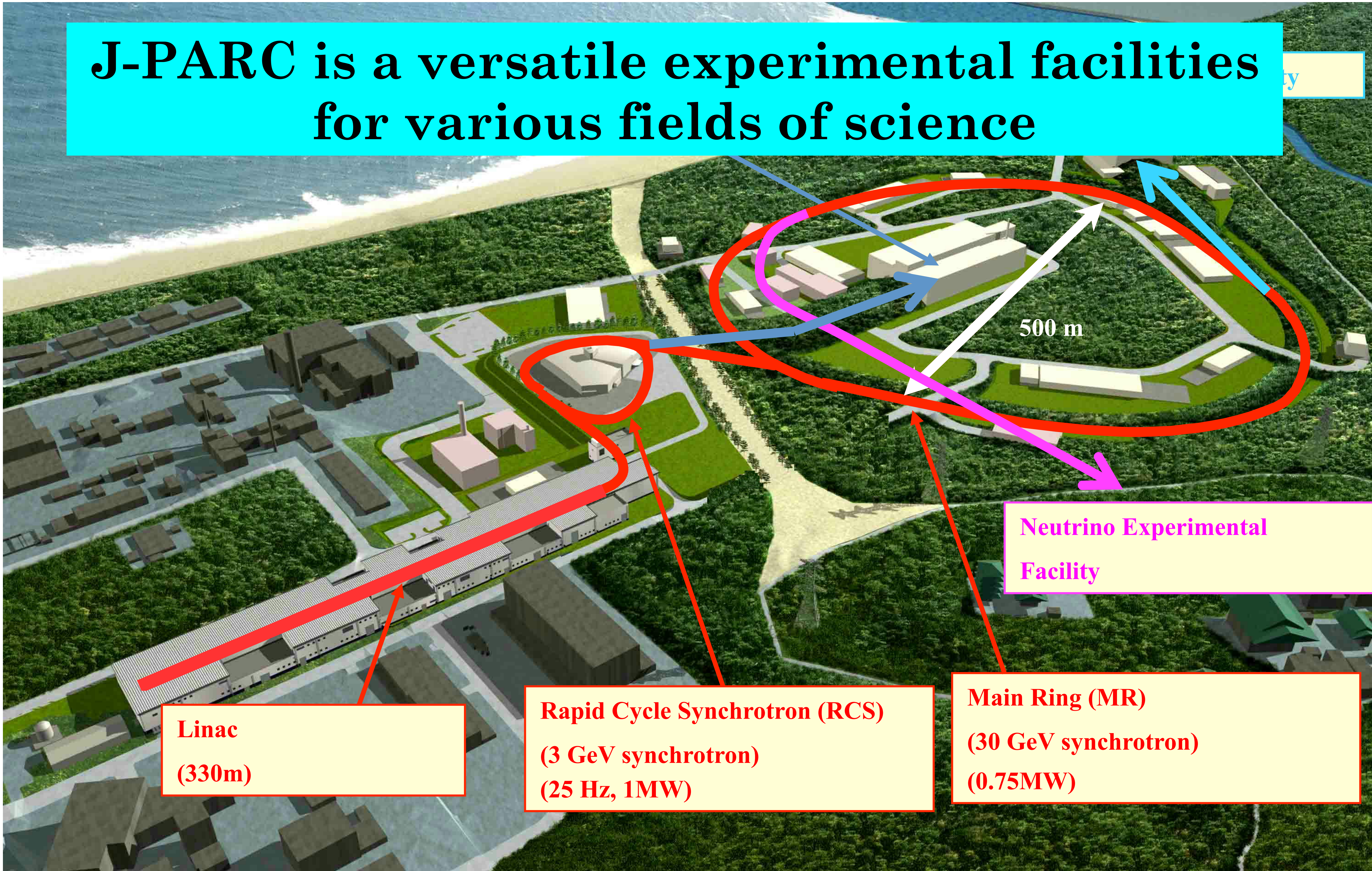
J-PARC



Materials and Life Science
Experimental Facility (MLF)
Hadron Experimental Facility
500 m
Neutrino Experimental
Facility
Linac
(330m)
Rapid Cycle Synchrotron (RCS)
(3 GeV synchrotron)
(25 Hz, 1MW)
Main Ring (MR)
(30 GeV synchrotron)
(0.75MW)

J-PARC


J-PARC is a versatile experimental facilities for various fields of science
500 m
Neutrino Experimental Facility
Linac (330m)
Rapid Cycle Synchrotron (RCS)
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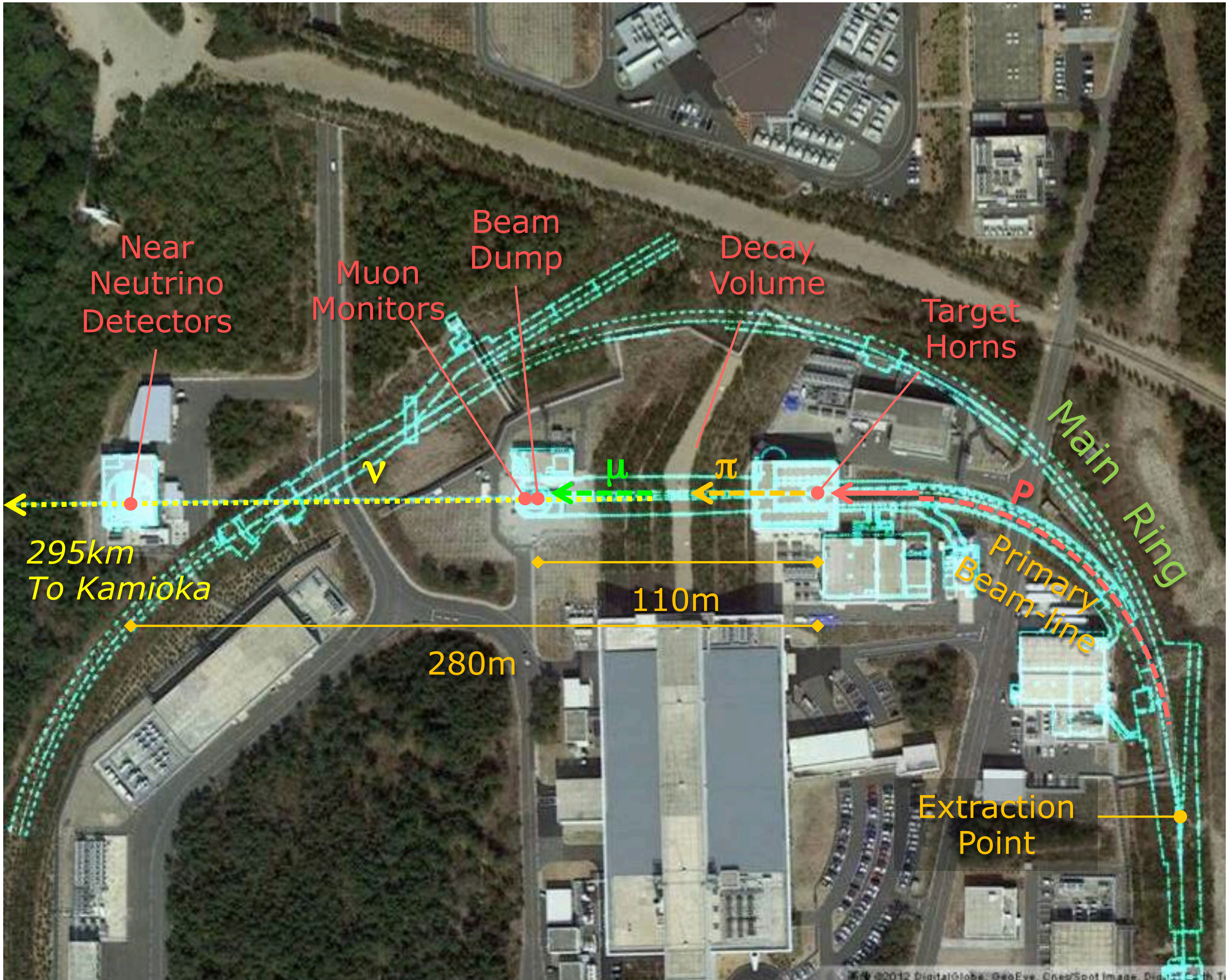
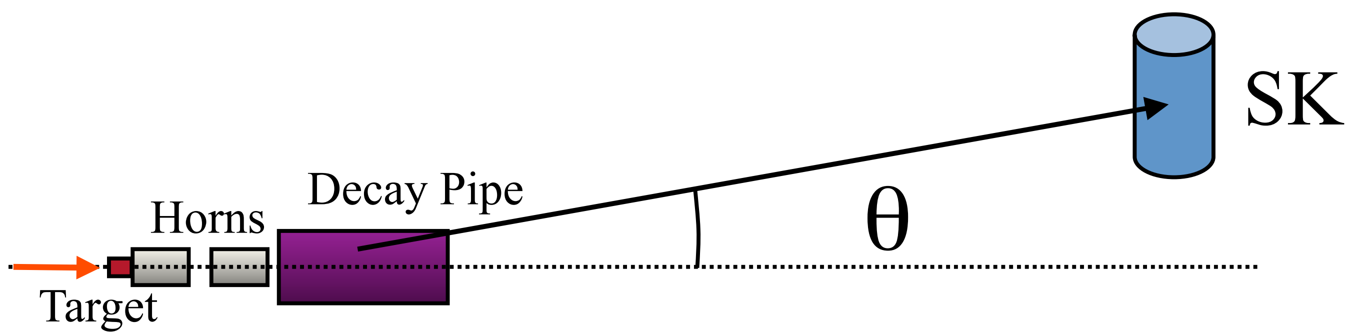
(25 Hz, 1MW)
Main Ring (MR)
(30 GeV synchrotron)
(0.75MW)

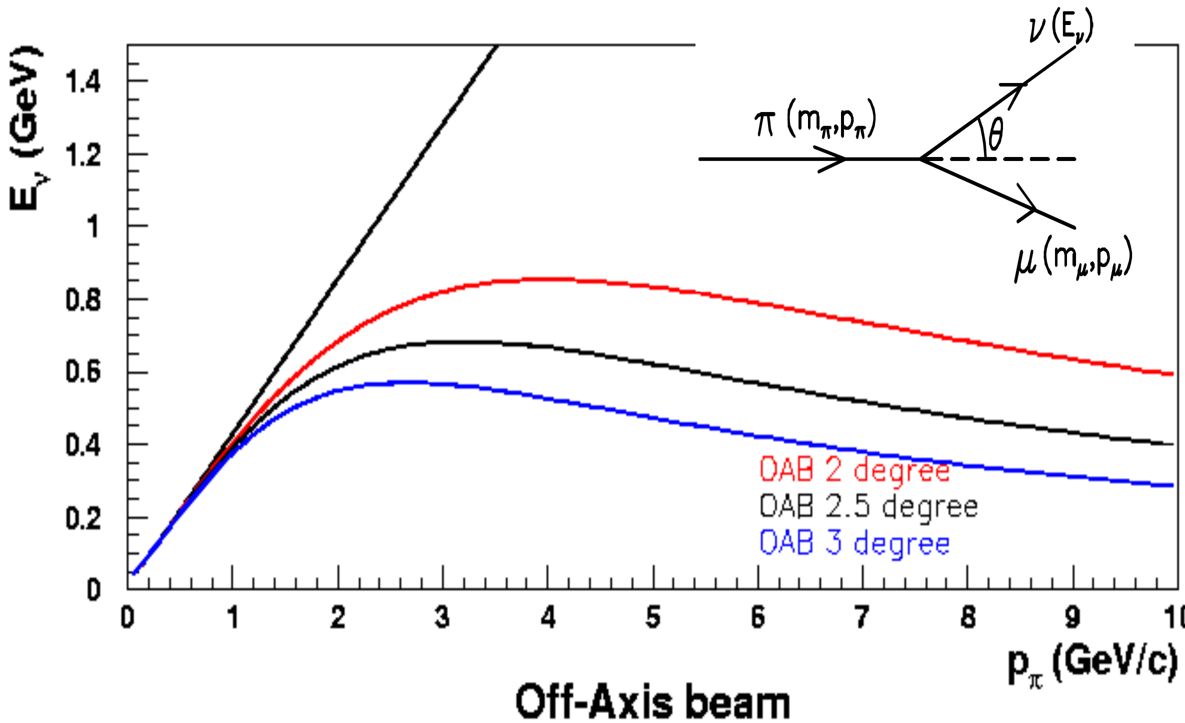
J-PARC Neutrino Beamline

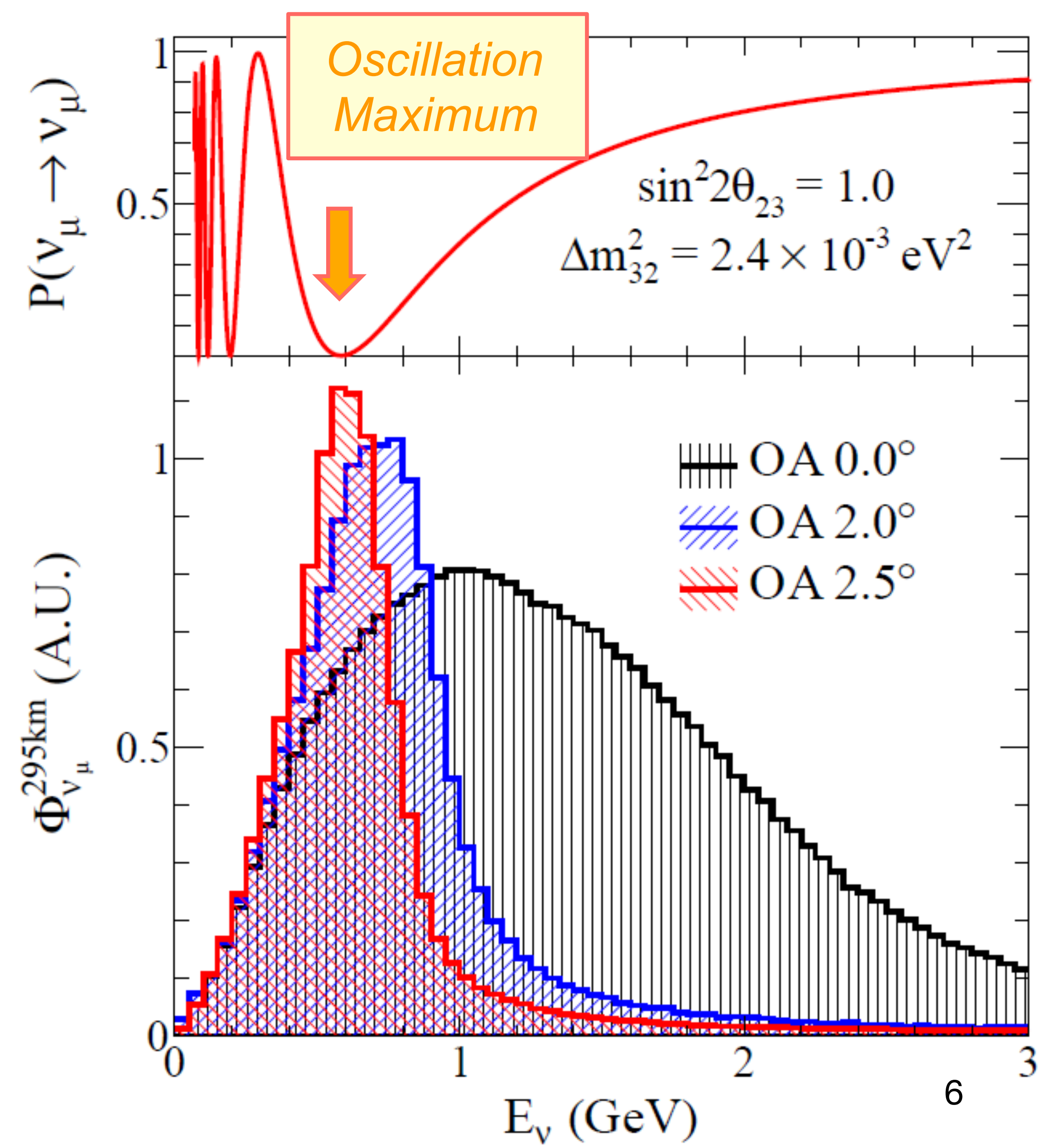


Features of J-PARC Neutrino Beamline

- **High intensity beam**
  - **750 kW** proton beam (30 GeV, **3.3×10^{14}** protons/pulse)
- **Off-axis neutrino beam (2~2.5°)**
  - **Narrow band beam** ~ 0.6 GeV
    - flux peak at 1st oscillation max.



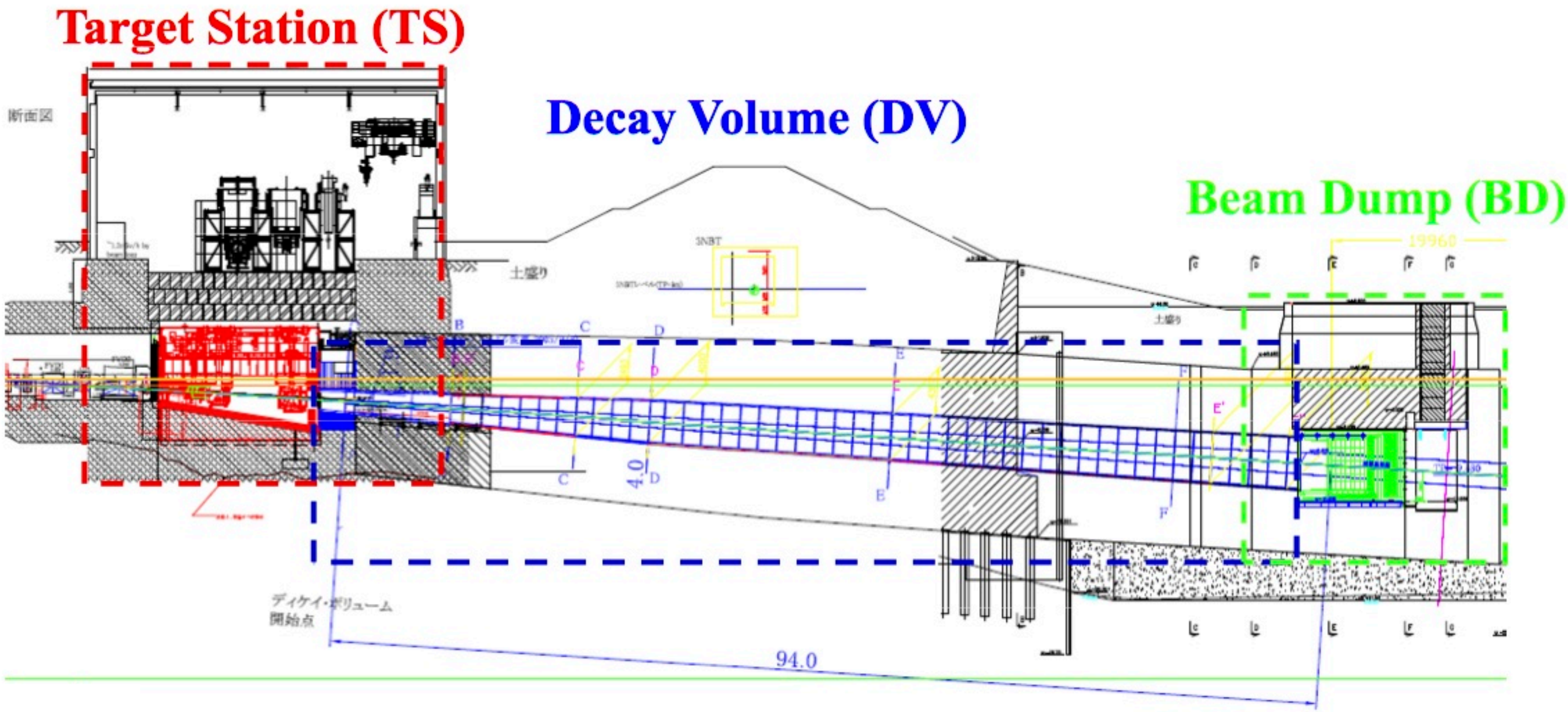




Design Philosophy of Neutrino Beamline

- **Tolerance for high power beam**
  - All beamline components designed for 750 kW beam
  - Equipments that cannot be replaceable after irradiation are designed for 3 or 4 MW beam.
- **Remote maintenance**
  - Secondary beamline equipments are highly irradiated with more than 1 Sv/h.
  - Beamline components inside Target Station can be replaceable remotely.

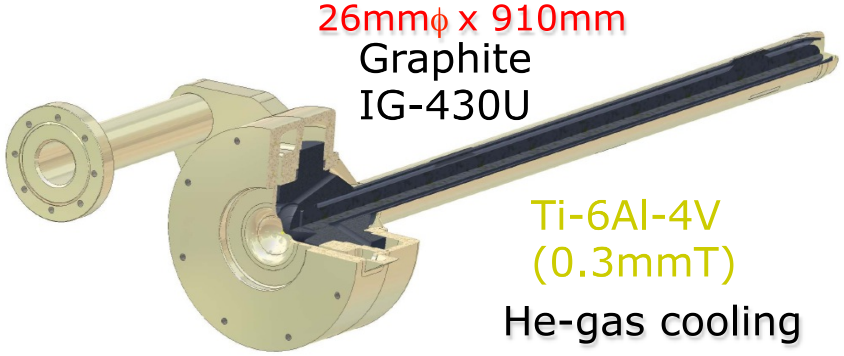
Secondary Beamline



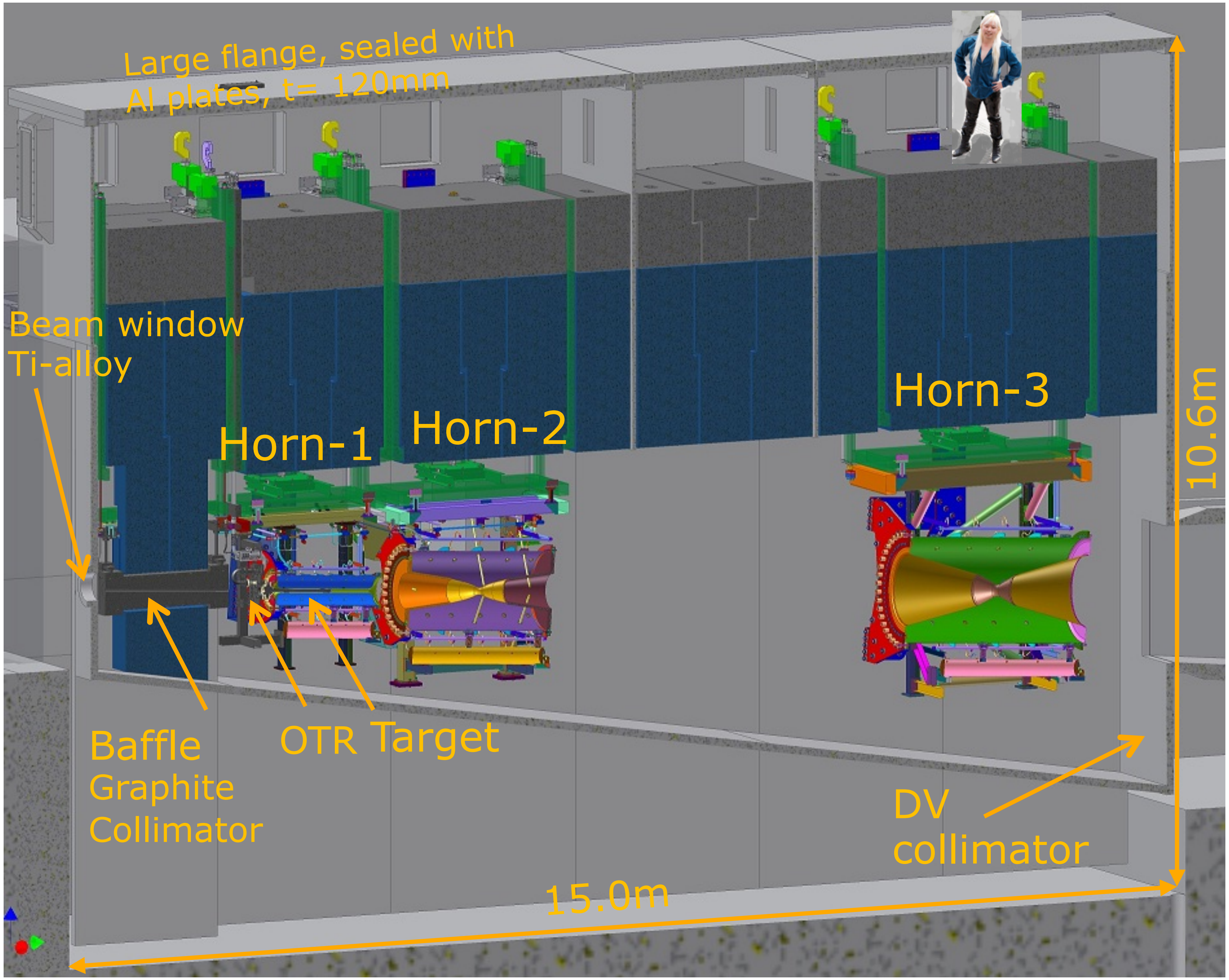
- Target Station (includes target and horns)
- Decay Volume
- Beam Dump

Target Station

Horn1



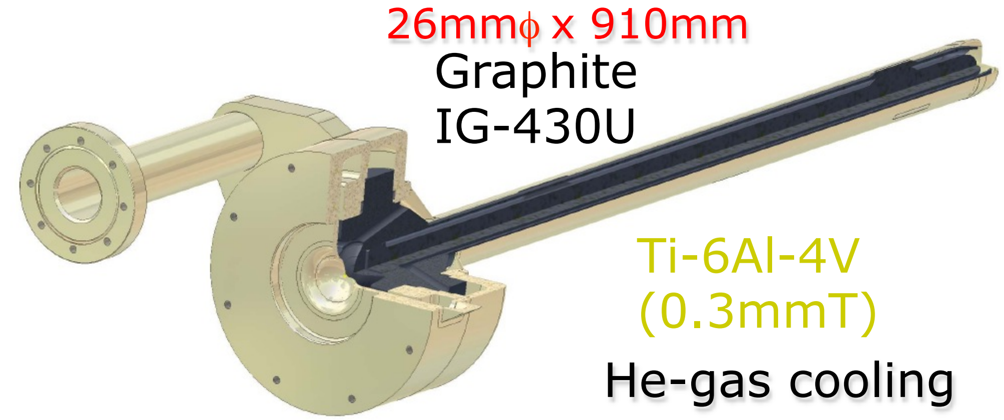
Target

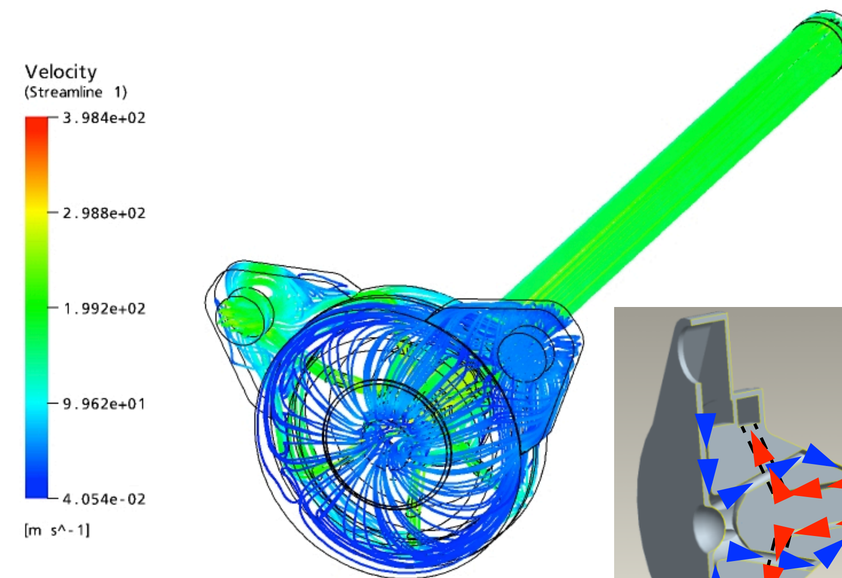


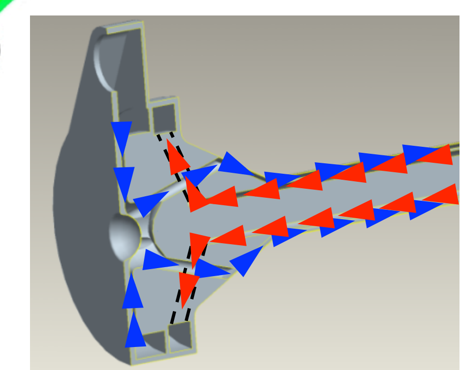
All equipments inside Helium Vessel can be replaceable

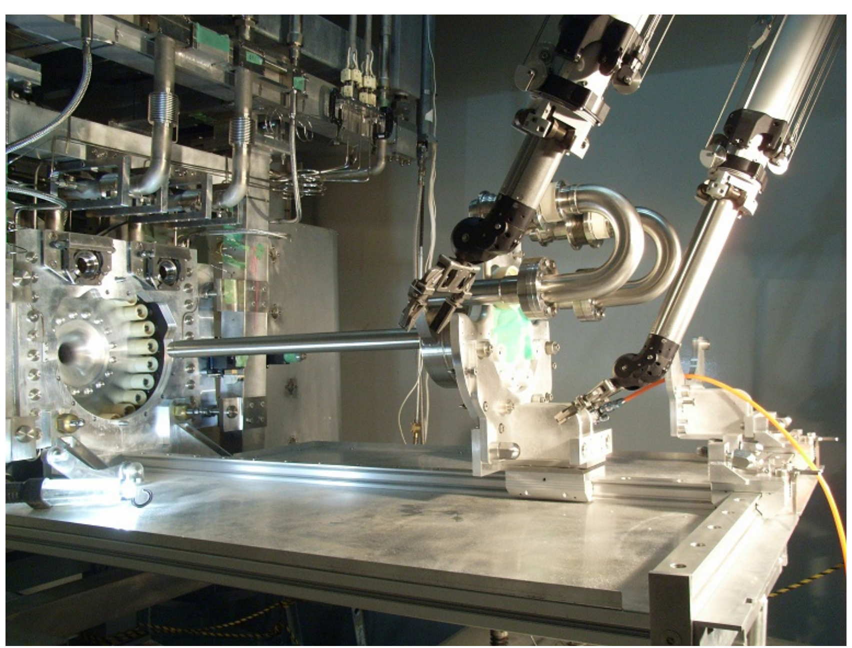
Target

- **Graphite target**
  - 26mmϕ × 910mm-long rod (IG-430U)
  - Covered by 0.3mm-thick Ti case
- **Helium cooling**
  - Cooled with 200m/s helium flow
  - Thermal stress @ ΔT~200K ⟹ ~7 MPa
    - Tensile strength 37 MPa
    - Radiation damage is key issue
- **Remote exchange**
  - Exchangeable with manipulators

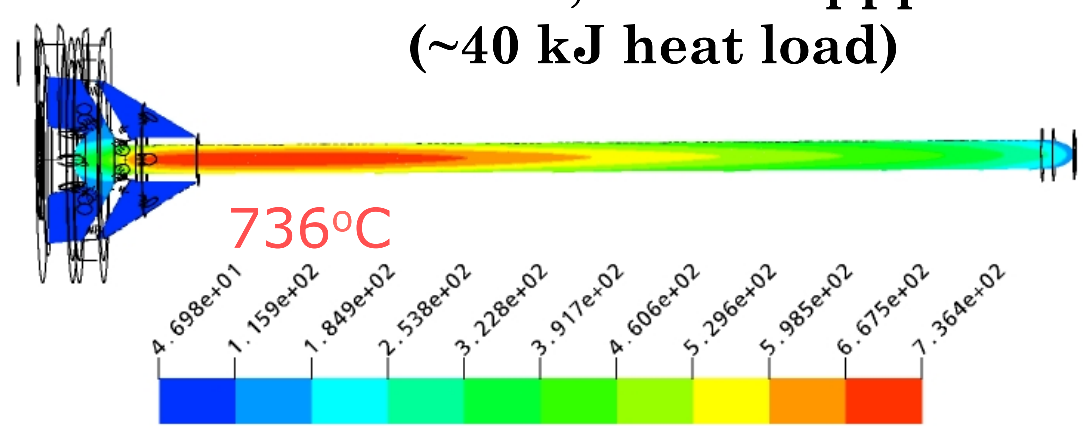








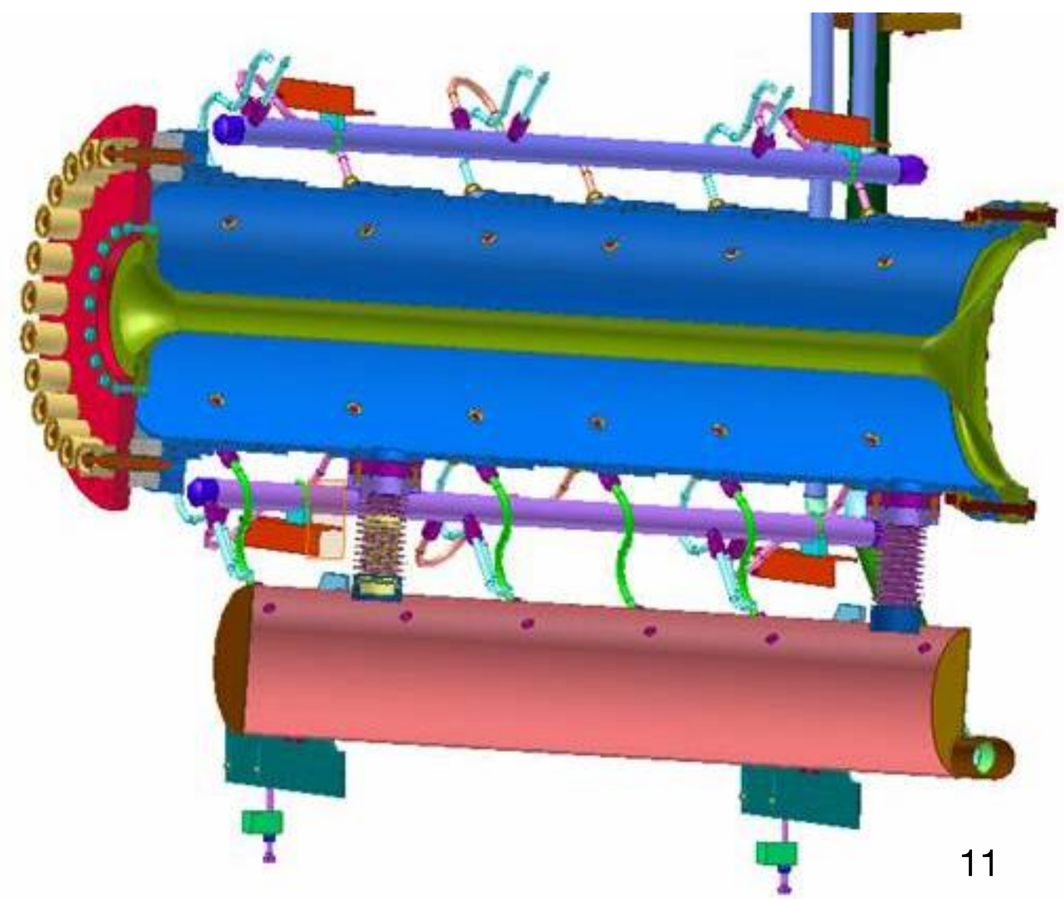
30 GeV, 3.3x10[14] ppp
(~40 kJ heat load)



ΔT~200K ~7MPa (Tensile strength 37MPa)

Magnetic Horn

- **Aluminum alloy conductors (A6061-T6)**
  - Coaxial cylindrical structure
    - inner=t3mm, outer=t10mm
  - Allowable stress=25 MPa (taking into account corrosion)
    - Safety factor ~2
- **320 kA pulsed current (rated)**
  - 2.1 T (max.) toroidal field
  - 2~3 ms pulse width
  - 2.48 s cycle ⟹ 1.3 s for 750 kW
- **Water cooled**
  - Total heat load 25 kJ @ 750 kW
    - 15 kJ (beam) + 10 kJ (Joule)
  - Spraying water to inner conductor

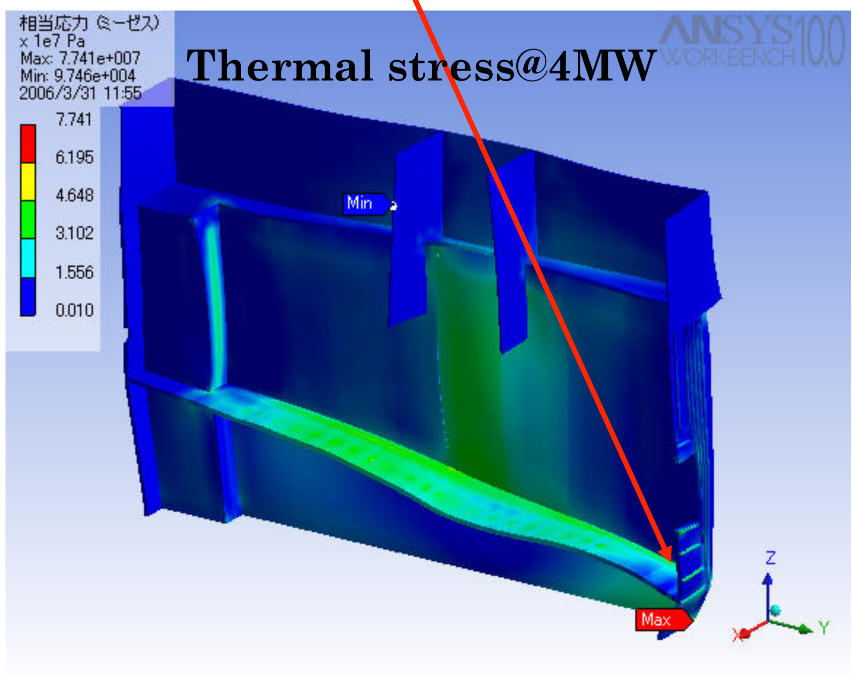


Target Station / Decay Volume / Beam Dump

- **Decay Volume (DV)**
  - 100 m long
  - 2~2.5° OA angle for SK and HK
  - water-cooled iron ⟹ 4 MW beam acceptable
- **Beam Dump (BD)**
  - Graphite core + water-cooled Al plates
  - Acceptable for 3 MW beam
- **Helium Vessel (TS, DV, BD)**
  - 1500 m^3 gigantic helium vessel
    - Filled with 1 atm. helium gas.

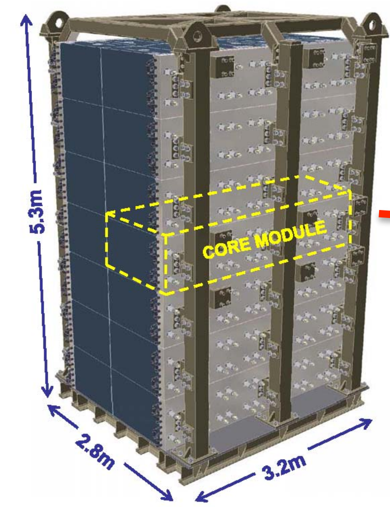
Helium Vessel @ TS

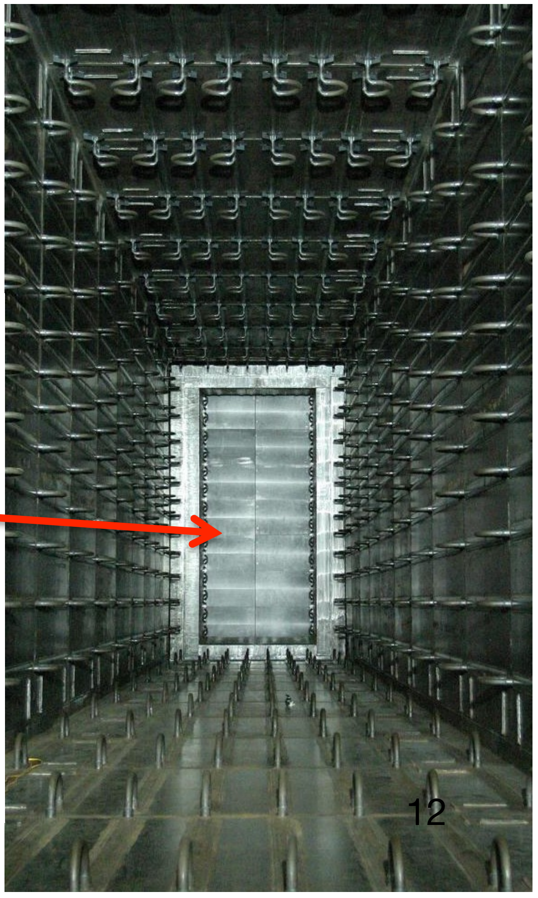
Maximum 77 MPa



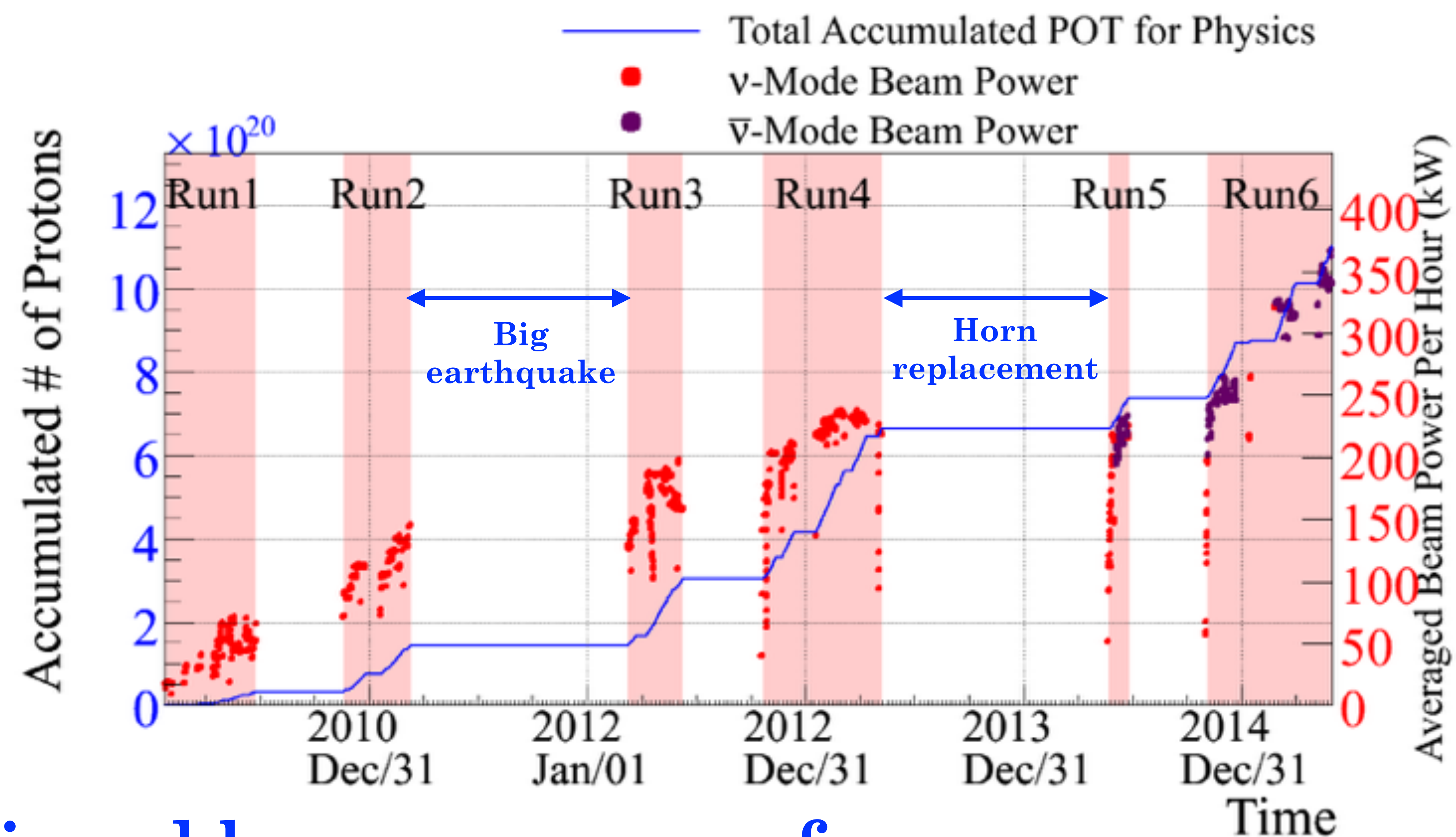
Decay Volume

Beam Dump





Operation Status



- **Achieved beam power so far**
  - **335~350 kW** continuous operation
  - **1.8×10^{14} protons/pulse** ⟹ world's highest intensity
- **Accumulated $1.1\text{x}10^{21}$ POT**
  - 7.0×10^{20} POT for neutrino mode
  - 4.0×10^{20} POT for anti-neutrino mode

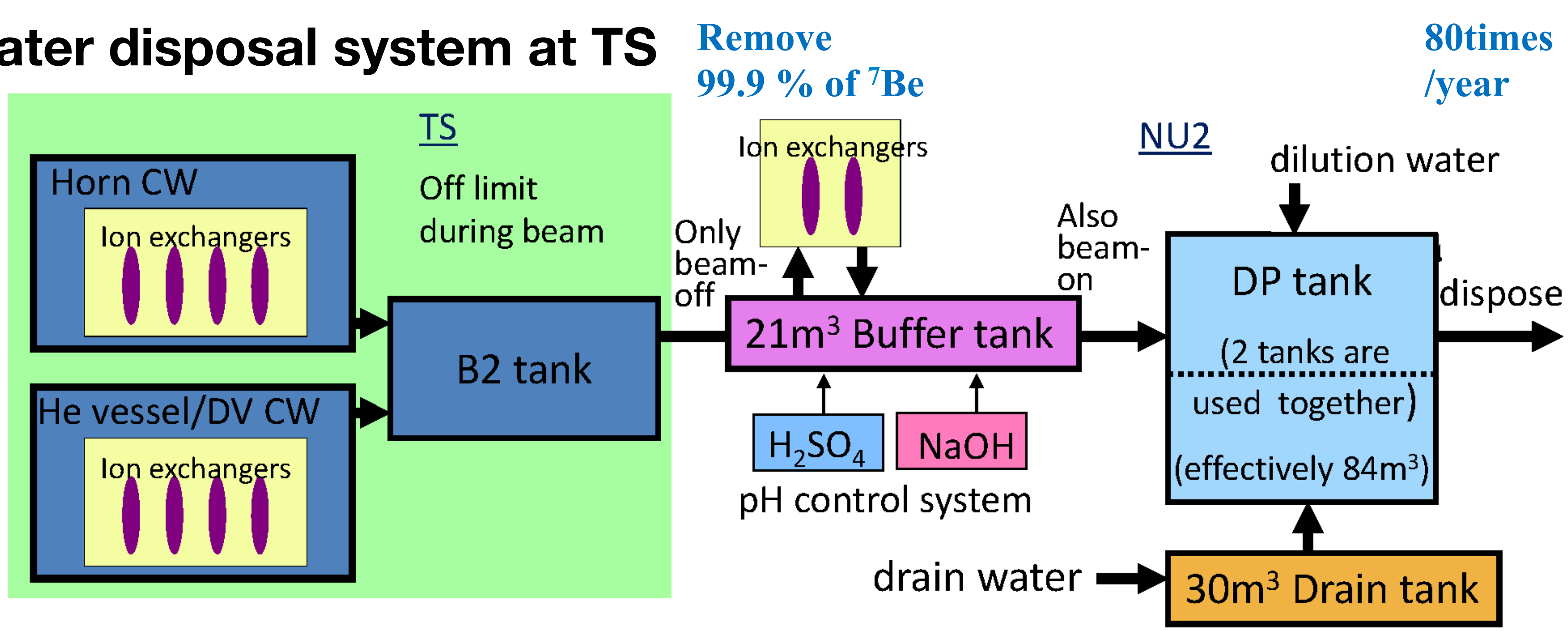
Limitation for High Power Beam

- **What are real problems in high power operation?**
  - Things to be well considered at design stage.
    - Mechanical strength
    - Cooling
    - Fatigue
  - These issues are major consideration, however,
- **In reality, beam power is limited by**
  - **treatment of radioactive wastes**
    - radioactive water.
    - radioactive air.
  - **production of hydrogen from water radiolysis**

Radio-active Water Disposal

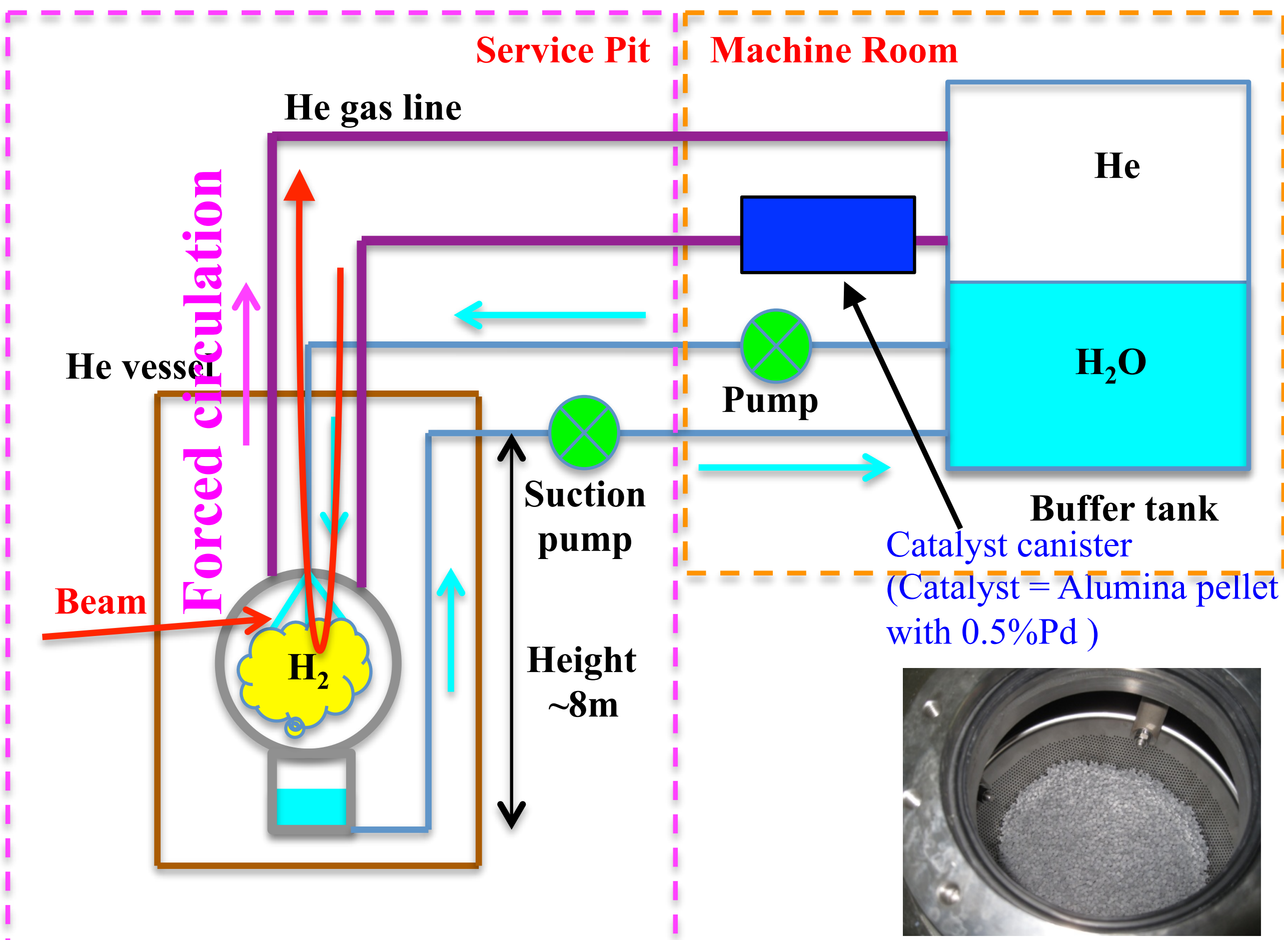
- **Radio-active water @ 750 kW**
  - ^{7}Be: 300 GBq/year ⇒ 99.9% removed by Ion Exchangers.
  - ^{3}T: 150 GBq/year ⇒ Diluted many times (80 times/year)
- **Limited dilution tank size → 0.5 MW**
  - Highly-activated water can be taken by tanker truck.
    - 750 kW will be accepted.
    - For BD/DV downstream cooling water, connection equipment for tanker truck was prepared and tested.

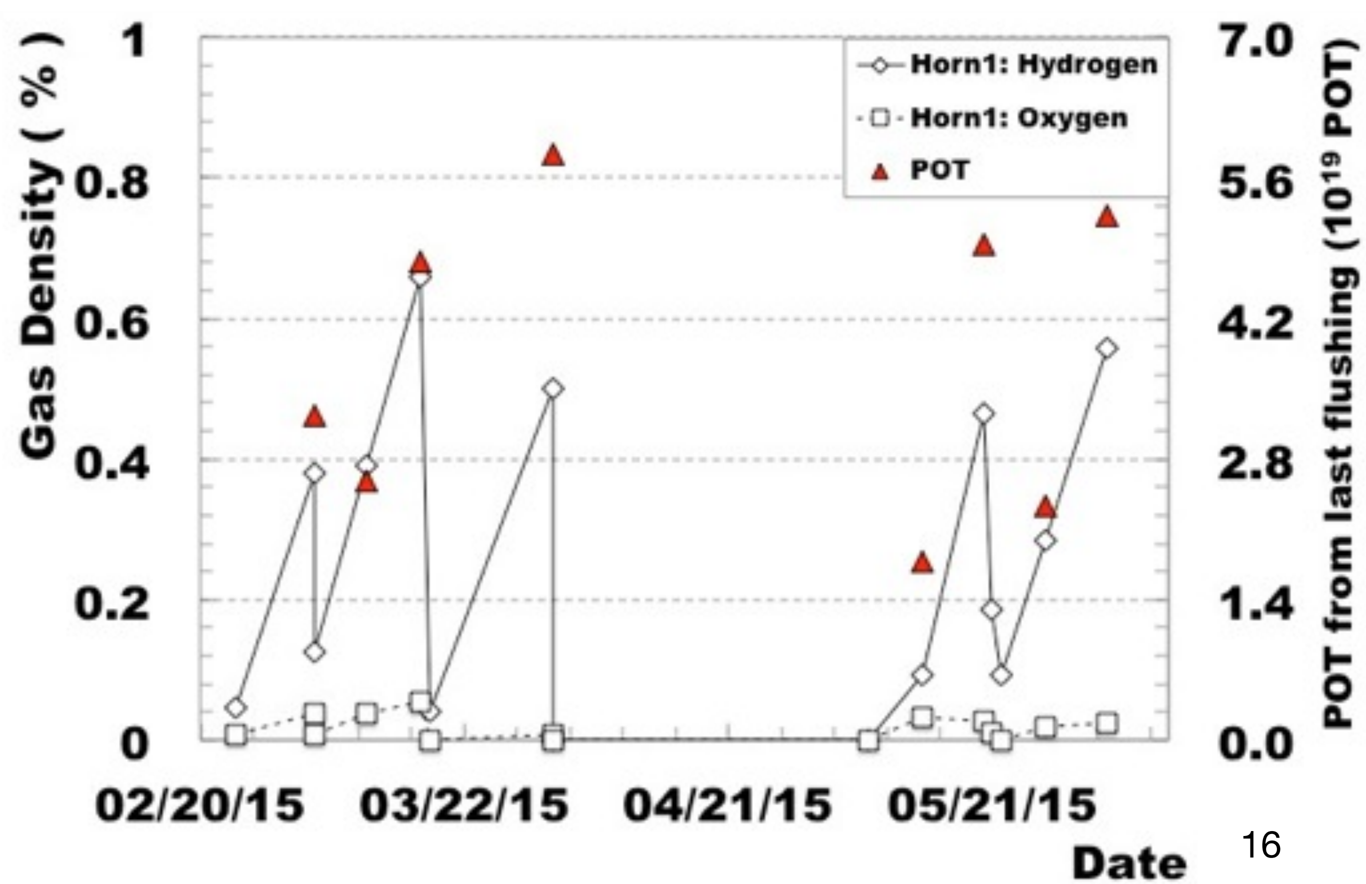
Water disposal system at TS



Hydrogen Production in Horns

- **H_2 produced by water radiolysis**
  - Expected production rate ~40L/day@750kW
- **Hydrogen removal by recombination**
  - **Forced flashing inside horns** ⟹ H_2 reaches catalyst efficiently
  - H_2 density after 2 week operation < 0.7% @335 kW
    - **1 MW beam acceptable** (w/ keeping H_2 density < 2%)
  - Degasifier will be introduced for higher recombination efficiency.





Current Acceptable Beam Power

Conponent	Limiting factor	Acceptable value
Target	Thermal shock	3.3×10^{14} ppp
	Cooling capacity	0.75 MW
Horn	Conductor cooling	2 MW
	Stripline cooling	0.54 MW
	Hydrogen production	1 MW
	Operation	2.48 sec. & 250 kA
He Vessel	Thermal stress	4 MW
	Cooling capacity	0.75 MW
Decay Volume	Thermal stress	4 MW
	Cooling capacity	0.75 MW
Beam Dump	Thermal stress	3 MW
	Cooling capacity	0.75 MW
Radiation	Radioactive air disposal	1 MW
	Radioactive water	0.5 MW

10 Year Term Plan of Beam Power Improvement

- **Design beam power = 750 kW**
  - Will be achieved in 2018
  - Beam power over 750 kW is recently being considered.
- **Aim for 1.3 MW beam by 2026**
  - Proton intensity = **3.2×10^{14} protons/pulse**.
  - Repetition cycle = **1.16 sec.** with new MR power supplies.
- **Can our beamline accommodate to 1.3 MW beam?**

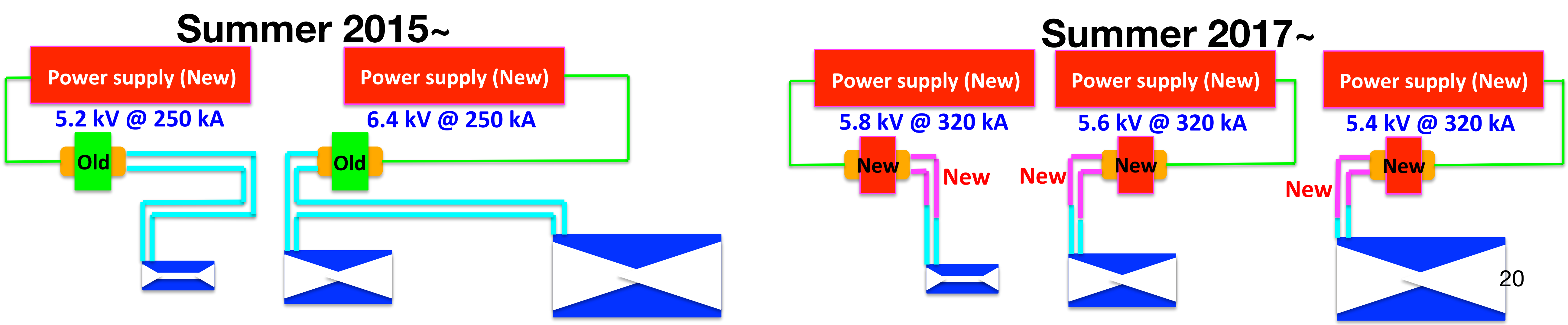
Beam Power	# of protons/pulse	Rep. rate
350 kW (achieved)	1.8×10^{14}	2.48 sec.
750 kW (proposed) [original plan]	2.0×10^{14} [3.3×10^{14}]	1.30 sec. [2.10 sec.]
1.3 MW (proposed)	3.2×10^{14}	1.16 sec.

Prospect for Hardware Upgrade

- **Cooling capacity**
  - Apparatuses themselves can withstand 1.3 MW beam.
  - Improvement of flow rate both for water and helium circulations is needed.
    - Replacement with larger pumps
    - Replacement with larger-size plumbing
    - ⟹ These will be feasible but need 1 year for modification.
- **Radiation**
  - Radioactive air
    - Reinforcement of air-tightness ⟹ 1.3 MW can be manageable.
  - Radioactive water disposal
    - Enlargement of dilution tank
      - Modification of existing tank ⟹ ~1.3MW
      - New facility building for water disposal ⟹ 2MW
        - 2 years for construction (no beam stop needed)

Horn Operation Improvement

- **Operation status**
  - 250 kA operation for physics data taking since 2010.
    - Mainly due to refurbishment of old K2K PS (rated 250 kA).
  - Currently, operated with 2.48 s cycle.
    - 1.3 s for 750 kW (not operated with the existing PS)
- **3 PS configuration for 320 kA and 1 Hz operation**
  - New power supply developed (2 PS's already produced).
  - Also, low impedance striplines newly developed.
- **Timeline**
  - Production of the last PS, transformers, part of striplines
  - Aim to start 320 kA operation from summer 2017.



Improved Acceptable Beam Power

Conponent	Limiting factor	Acceptable value
Target	Thermal shock	3.3×10^{14} ppp
	Cooling capacity	>1.5 MW
Horn	Conductor cooling	2 MW
	Stripline cooling	1.25 MW
	Hydrogen production	>1 MW
	Operation	1 sec. & 320 kA
He Vessel	Thermal stress	4 MW
	Cooling capacity	>1.5 MW
Decay Volume	Thermal stress	4 MW
	Cooling capacity	>1.5 MW
Beam Dump	Thermal stress	3 MW
	Cooling capacity	>1.5 MW
Radiation	Radioactive air disposal	>1 MW
	Radioactive water	0.75→1.3 or 2 MW

Summary

- **J-PARC Neutrino Beamline**
  - High intense narrow band beam.
  - Designed for 750 kW beam
- **Operation status**
  - 350 kW stable operation so far.
  - Need improvements on some components such as radiation issues, hydrogen production and so on.
- **Beamline improvement**
  - 1.3 MW beam scenario is being discussed.
  - Necessary improvements
    - Higher cooling capacity for every components
    - Treatment of radioactive wastes
    - Horn operation (320 kA and 1 Hz)

Supplemental Slides

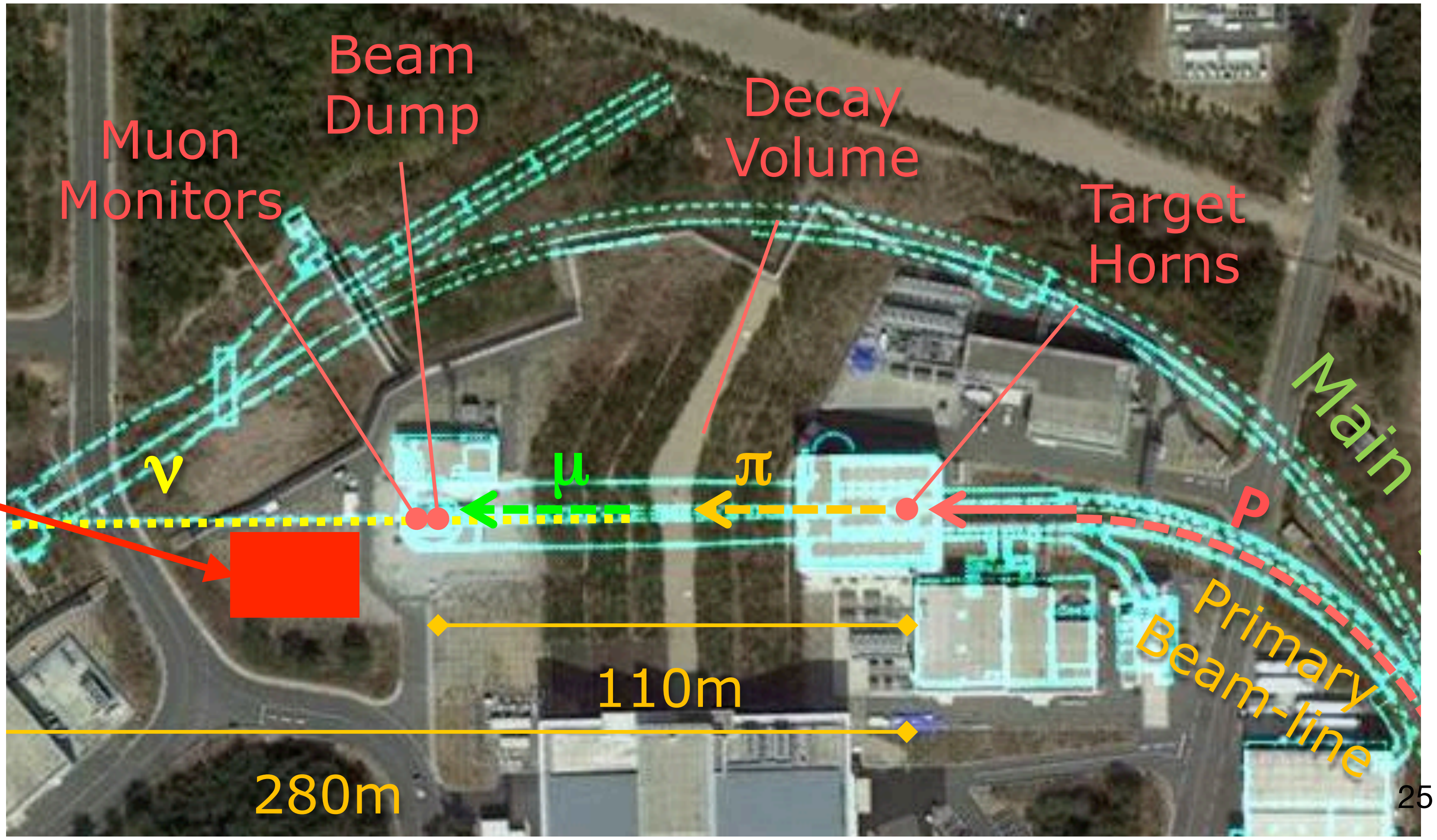
Stripline Cooling

- **Forced helium flow for stripline cooling.**
  - Large heat deposit at Horn2 (due to defocused pions)
  - Insufficient helium flow rate for Horn2. → 0.54 MW
  - **Double flow rate for Horn2** → **1.25 MW**
- **Water-cooled striplines**
  - Necessary when beam power goes beyond 1 MW.
  - Under conceptual design.

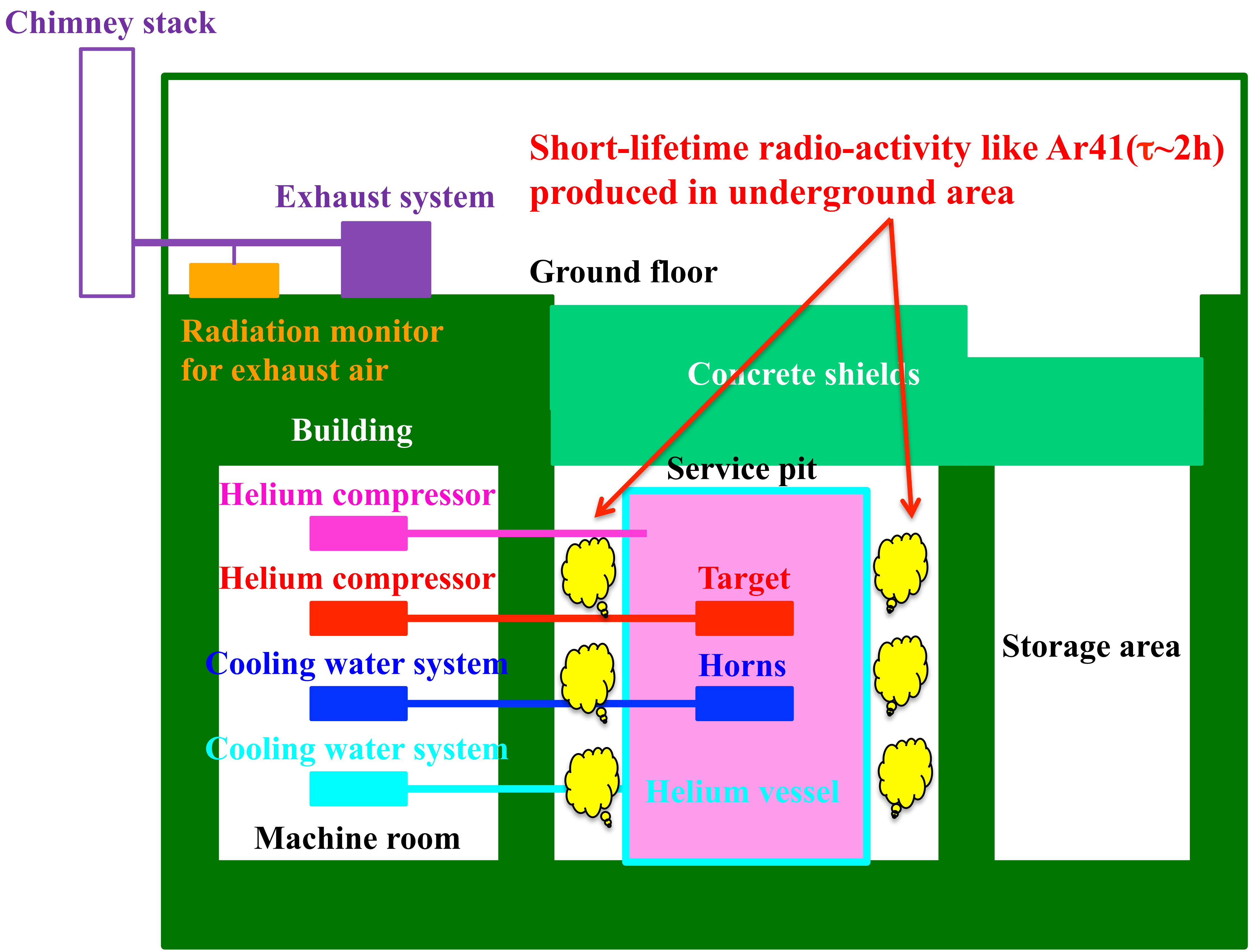
	Horn1	Horn2	Horn3
Heat flux per stripline plate (J/m^2) @ 1.3 MW			
Total (Beam + Joule)	214	1066	141
Acceptable Beam Power			
w/ current flow rate	2.10	0.54	3.46
w/ double flow rate	-	1.25	-

Radio-active Water Disposal

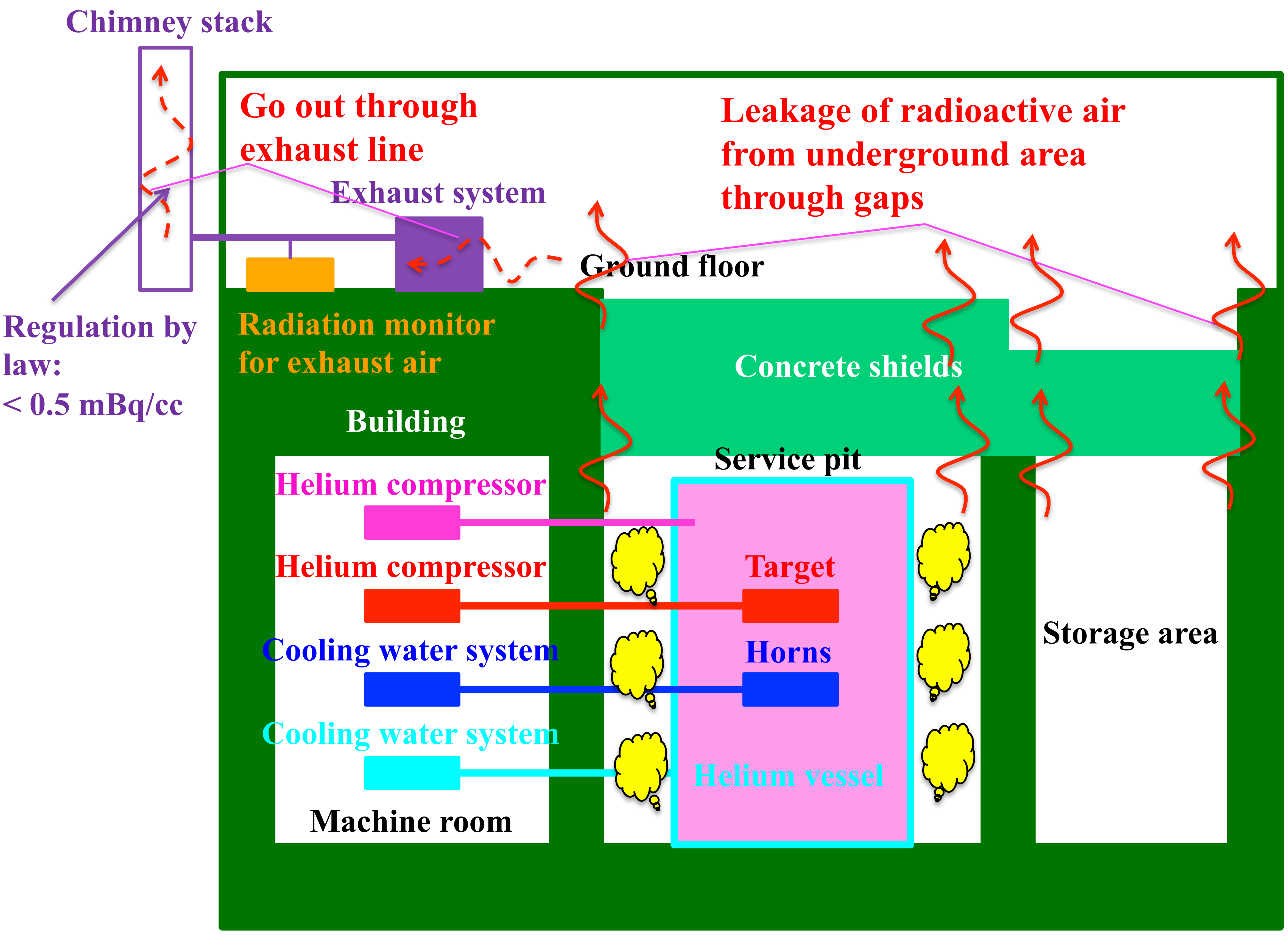
- **For beam power > 750 kW,**
  - larger dilution tanks are necessary.
- **Solutions**
  - Enlarging the existing dilution tank ⟹ 1.3 MW at max.
  - New facility building for radio-active water disposal ⟹ **2 MW**
    - Its operation can be started from 2018 in earliest case.



Radioactive Air



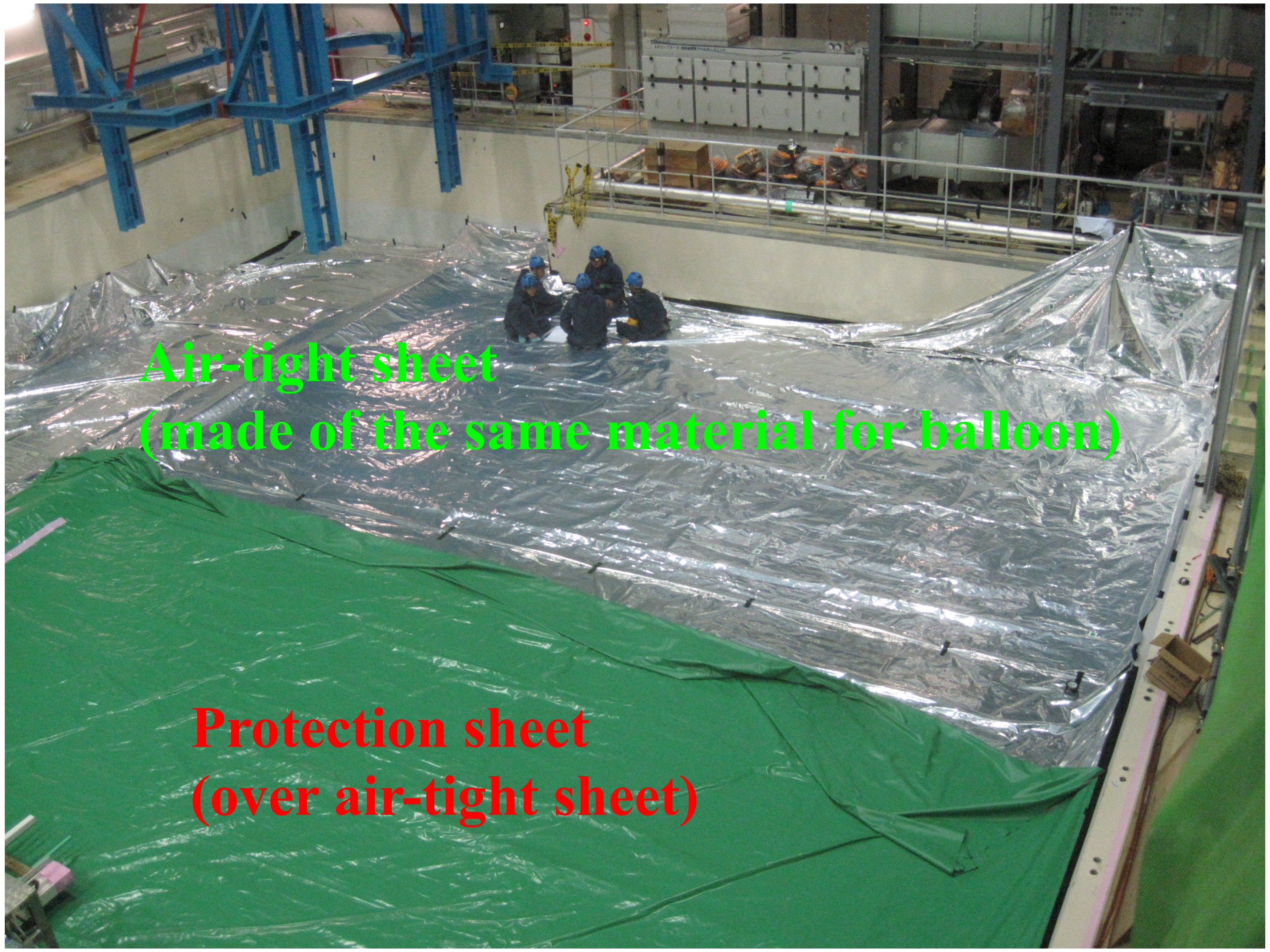
Radioactive Air



Improvement of Air Tightness

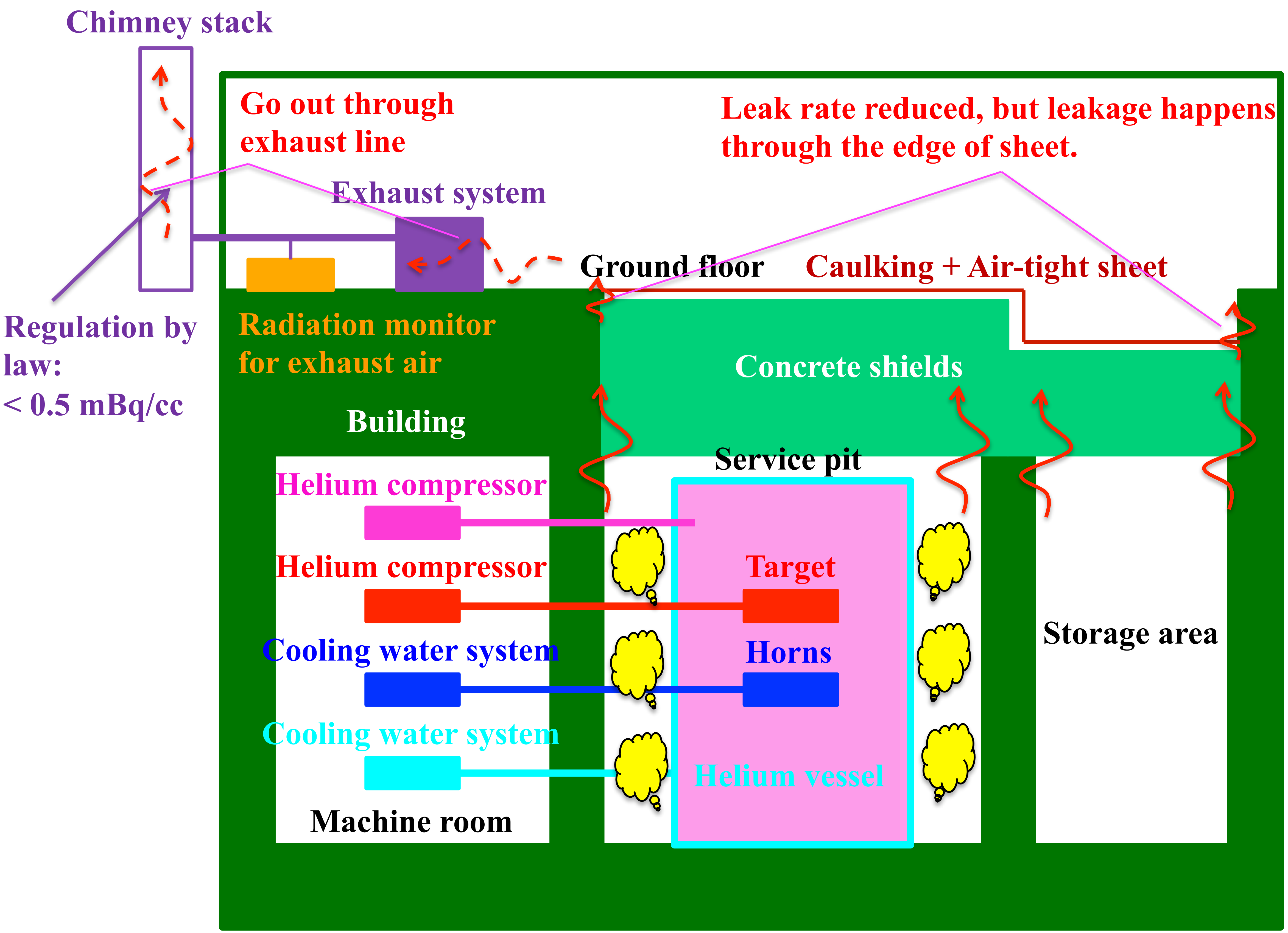
Caulking between concrete shields

Lay the air-tight sheet

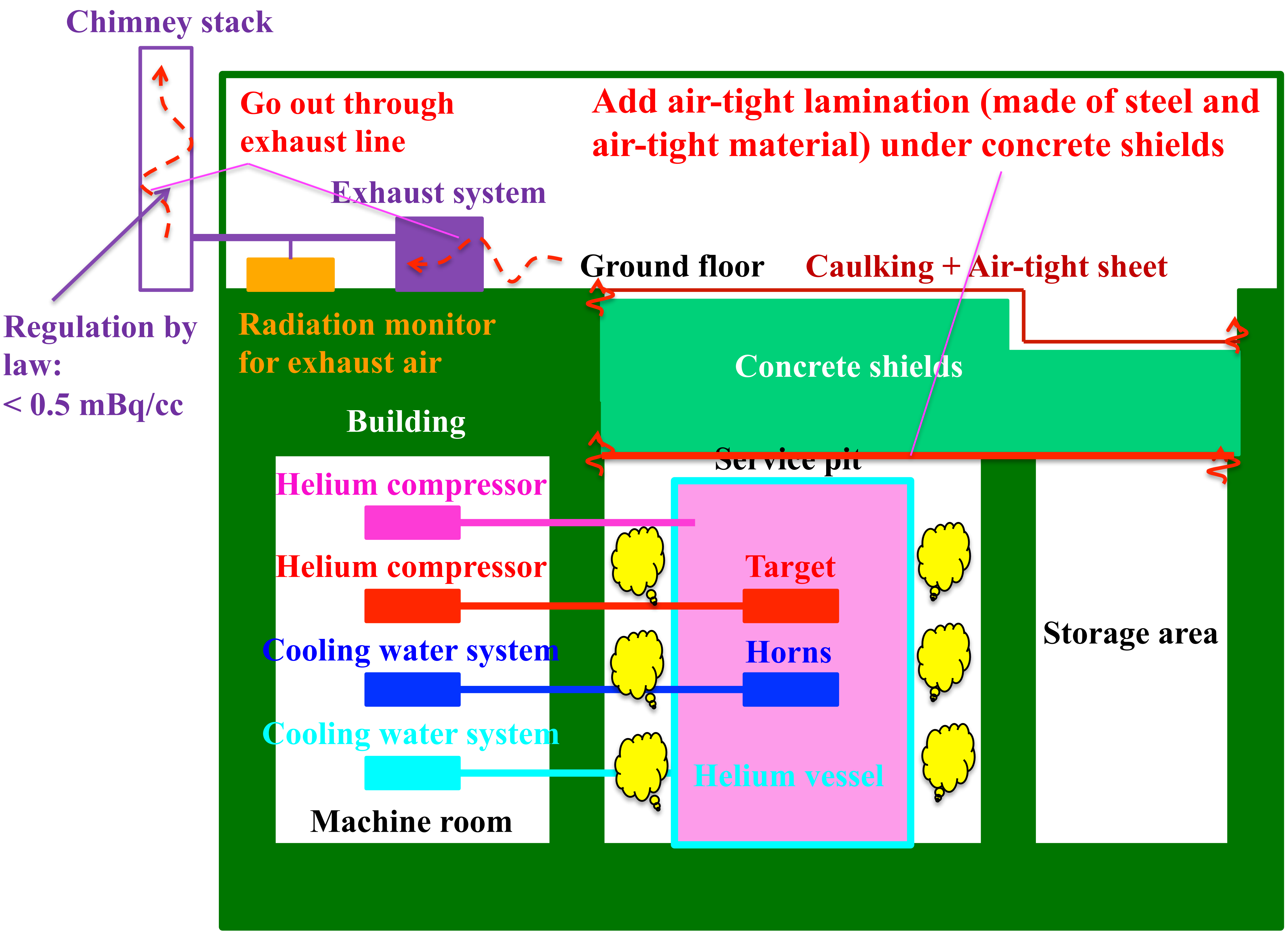


Lay the protection sheet under air-tight sheet

Radioactive Air (Current)

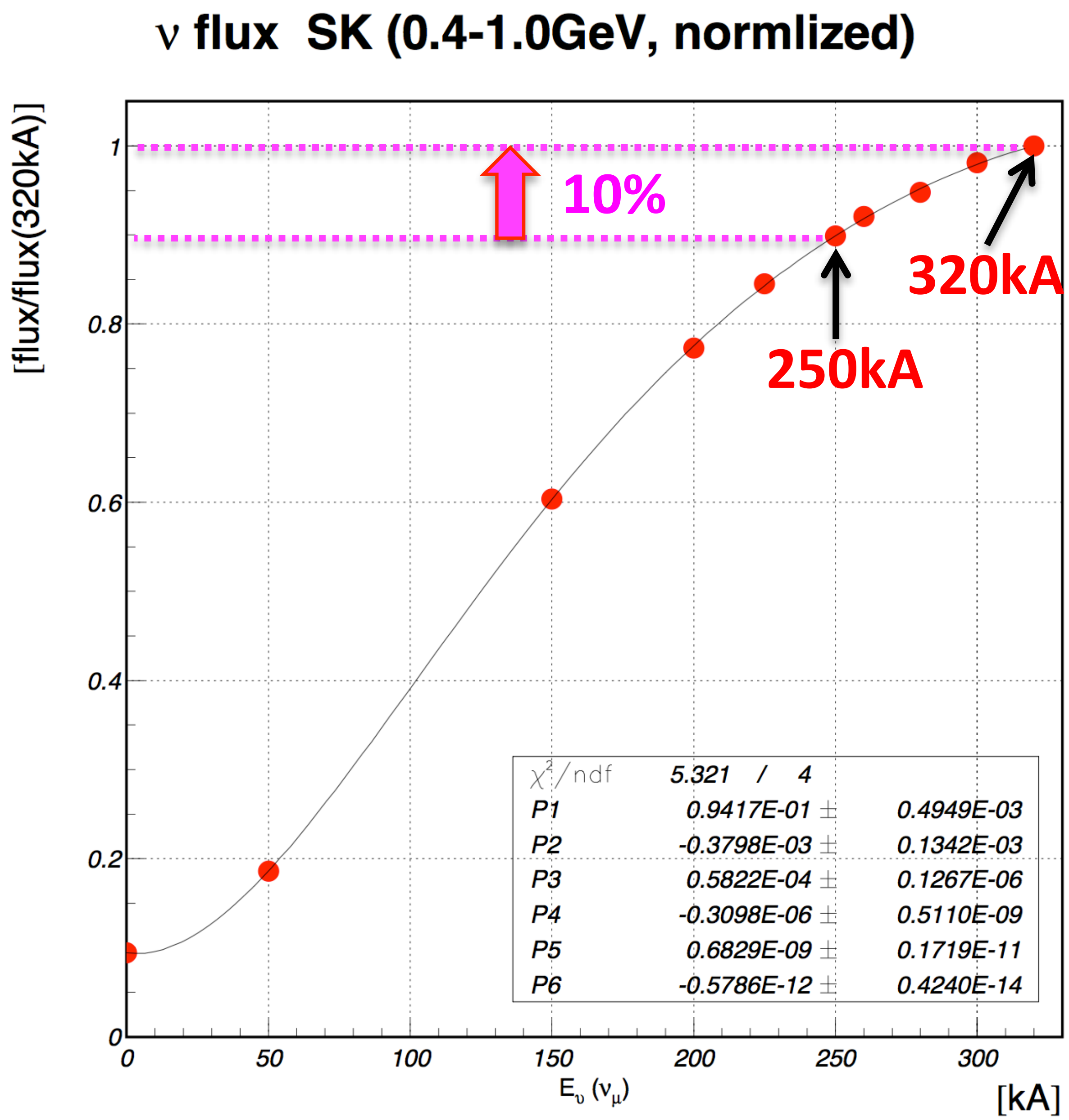


Radioactive Air (Improvement Plan)



Flux Improvement by Neutrino Beamline

- **Magnetic horn current**
  - 250 kA $\Longrightarrow$ 320 kA (rated)
  - **10 % improvement of neutrino flux at far detector**

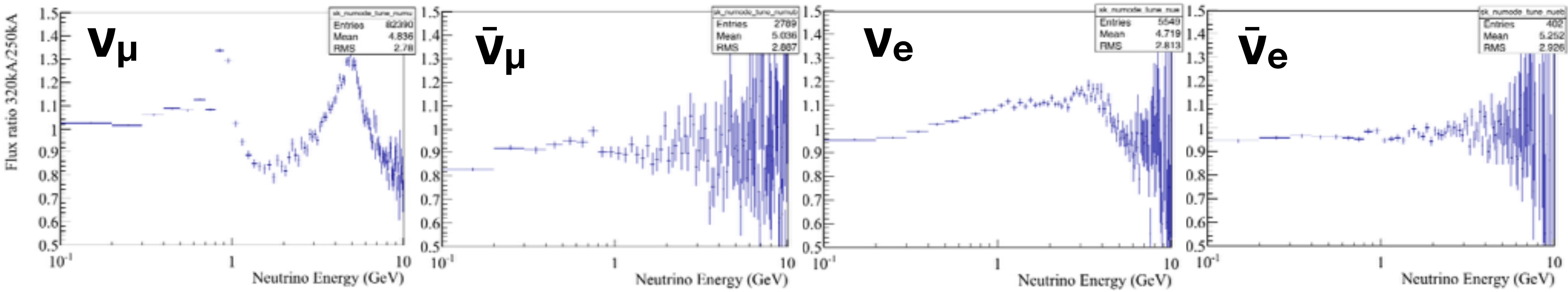


Courtesy of T.Nakadaira

Flux Improvement by Neutrino Beamline

- **Another benefit of 320 kA operation**
  - **Low contamination of wrong-sign neutrino background**
    - 5~10% reduction at peak (E_ν~0.6 GeV)

Neutrino mode



Anti-neutrino mode